ALS Accelerator Update

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ALS Accelerator Physics Group

- List of Upgrades during FY05
- Status of Top-off Upgrade
- Upgrade of fs-Slicing Source/First In-Vacuum ID in ALS
- Elliptically Polarizing Undulators
- Gap in Fill Pattern, Phase Transients and fs-Slicing
- What is next: Upcoming Installations/Improvements

Introduction

- User requirements are constantly evolving (user experiments get more sensitive)
  - —Performance of few years ago is not sufficient now!
  - —Have to constantly improve stability and in some cases brightness.
  - —Adding new capabilities that make facility more complex/complicated
- Future upgrades will require further evolution of stability, etc.
- Have to optimize complete system of accelerator+beamlines
  - —Close cooperation of all groups

Accelerator improvements last year

- **New Capabilities (non Top-Off):**
  - — New in-vacuum undulator (first at ALS) installed in straight 5, including chicanes, photon stops, …
    - 5.5 mm min. magnetic gap, installed in upstream half of straight
  - — Converted more skew quadrupoles for higher strength for fs-slicing vertical dispersion bump
  - — Installed 3rd EPU (for PEEM-3, 11.0.1), first chicaned straight filled with 2 undulators
    - Orbit, tune, skew feed-forward work well together for both devices

- **Top-off Preparation:**
  - — Installed first prototype of new adjustable scraper/collimator for top-off radiation protection
  - — Modified beamline 4.0 to allow top-off injection tests with beamline shutters open
  - — Many more top-off work done outside accelerator

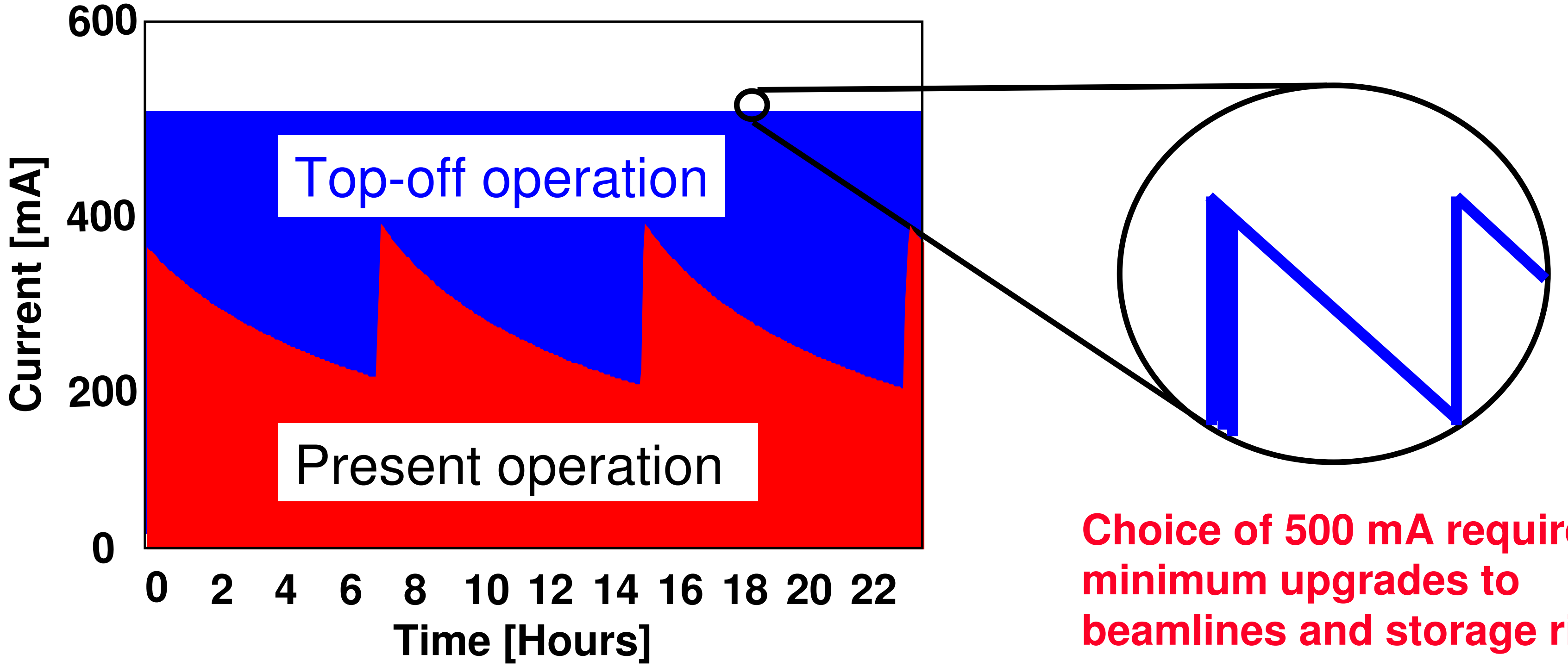
More Hardware Work

- **Stability/Performance:**
  - Complete storage ring was surveyed + some subset of individual magnets realigned
    - Improved temperature correction and analysis
  - Finished installing skew quadrupole compensation coils in all 4 EPU vacuum chambers
    - Further improved stability of vertical beamsize
  - New set of computer interface cards – improved fast orbit feedback operation
- **Reliability:**
  - Second set of waveguide higher order mode (HOM) dampers in main RF cavities
    - Further improved multibunch stability leading to higher reliability (now nearly passively stable with HC)
  - Replaced original fast orbit feed-forward on EPUs with digital version
    - Incorporates skew quadrupole correction, more reliable, lower noise

What is Top-off operation of the ALS?

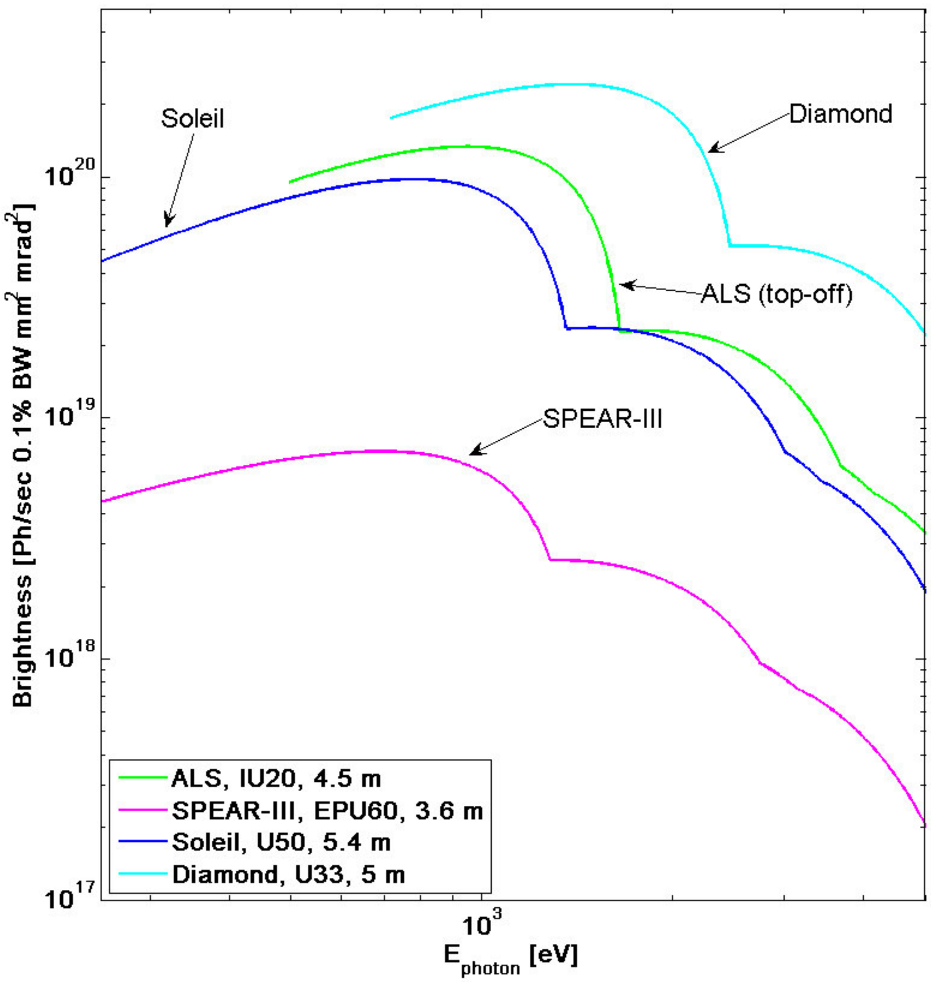
Top-off operation is quasi-continuous injection into the storage ring

Beam current history for one day



Choice of 500 mA requires minimum upgrades to beamlines and storage ring

Brightness comparison 2007



- **Top-off upgrade and current undulator technology: ALS competitive with best newer light sources around 1 keV**
- **Detailed beam parameters for comparison listed on next slide**
- **Undulator and beam parameters expected for 2007 are plotted**

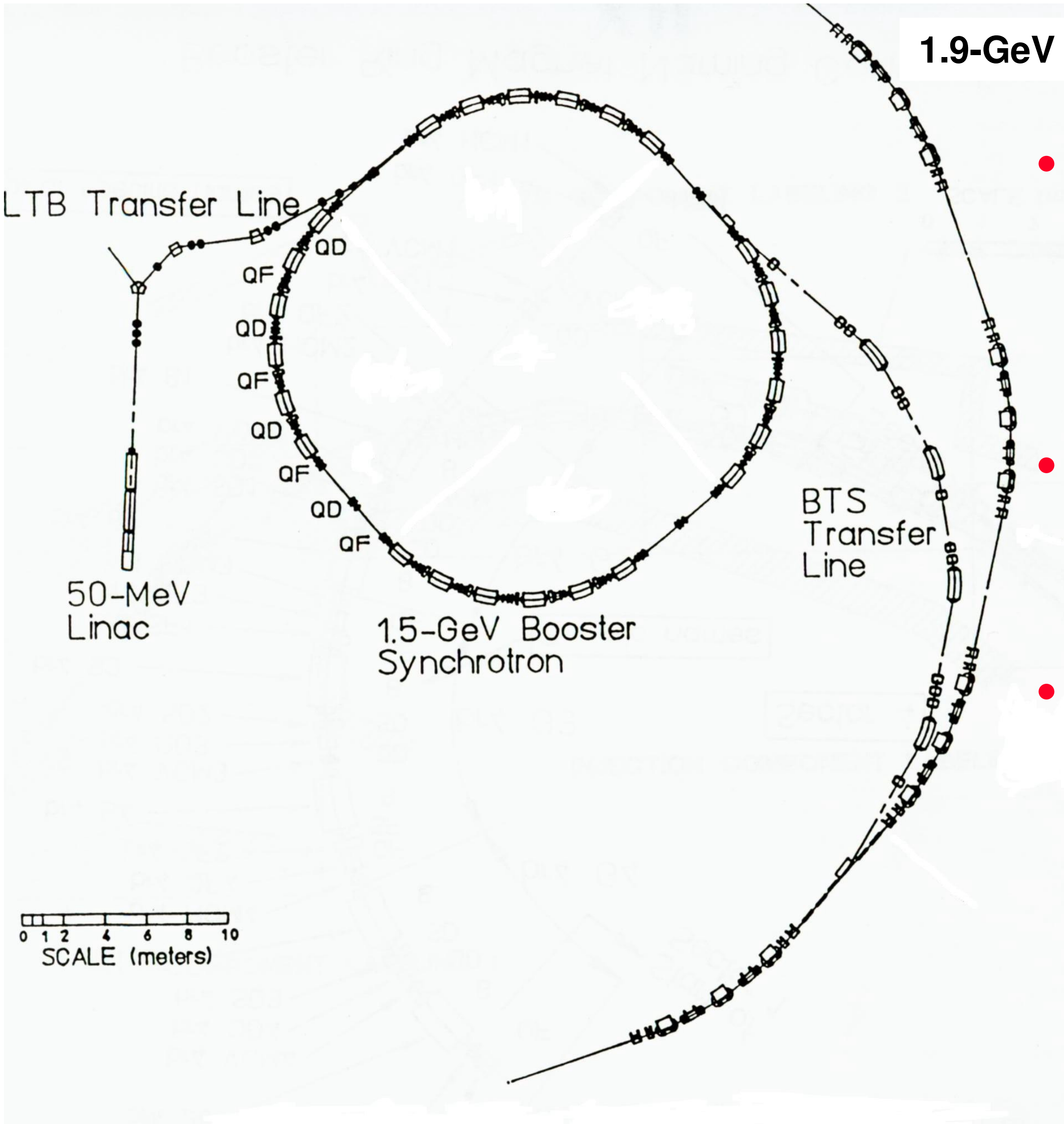
Beam parameters, ALS and other Light Sources

Param. \ Ring	ALS (top-off)	Diamond	Soleil	Spear III	APS
E [GeV]	1.9	3.0	2.75	3.0	7.0
I [mA]	400 (500)	300	500	500	100
ε_x [nm] (effective)	6.4	3.0	5.6	18.9	3.0
σ_x [μm]	299	123	384	450	276
σ_x' [μr]	21.4	24.2	14.5	42.0	11.3
ε_y [pm]	140 (30)	27	37	174	25
σ_y [μm]	23 (8)	6.4	8	29	11.2
σ_y' [μr]	6 (3.6)	4.2	4.6	6	2.2
Energy Spread [%]	0.097	0.096	0.1016	0.096	0.096

(Reduced) Scope of the Top-off Upgrade

- Upgrade injector to enable full energy injection
- Improve diagnostics and other existing systems where necessary for reliability
- Upgrade radiation safety system to allow injection with shutters open
- Minimize injection transients to reasonable levels and provide a gating signal
- Migrate to higher current and smaller vertical beamsizes
- Transition to Top-off with minimal negative impact to users

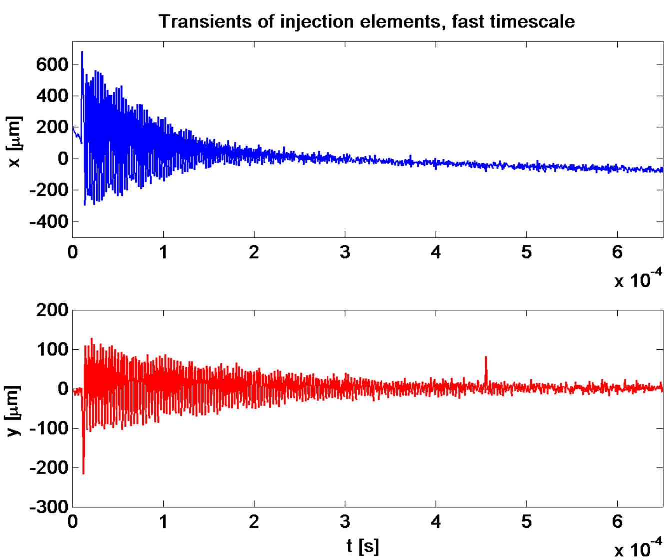
Upgrade injector to enable full energy injection

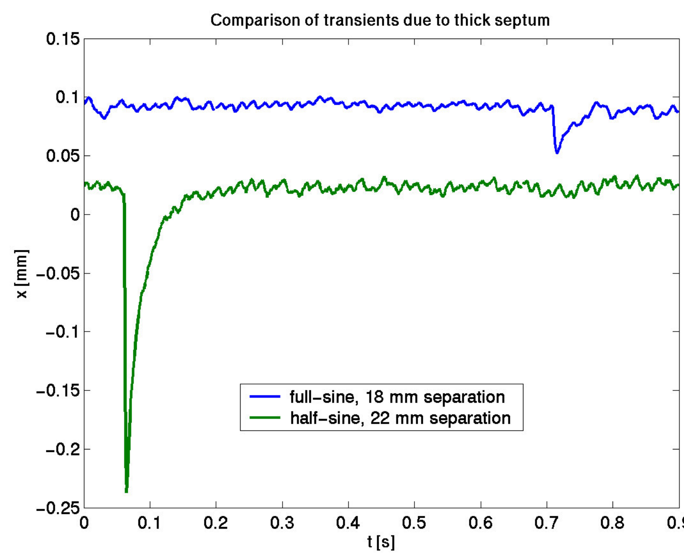


- **New booster+BTS DC Power Supplies and Controls**
- **Upgrade of the booster RF system (e.g. power)**
- **Modifications of the Pulsed Magnets and Supplies**

Orbit distortion due to injection elements

- Similar problem at all top-off facilities – we try to combine best mitigation approaches
  - Incoming beam is only small fraction of total intensity
  - But injection elements also perturb stored beam
- Conducted experiments with users
  - Most experiments insensitive to any distortion
  - Very few experiments (STXM, IR) see no-closure of bump and will require gating



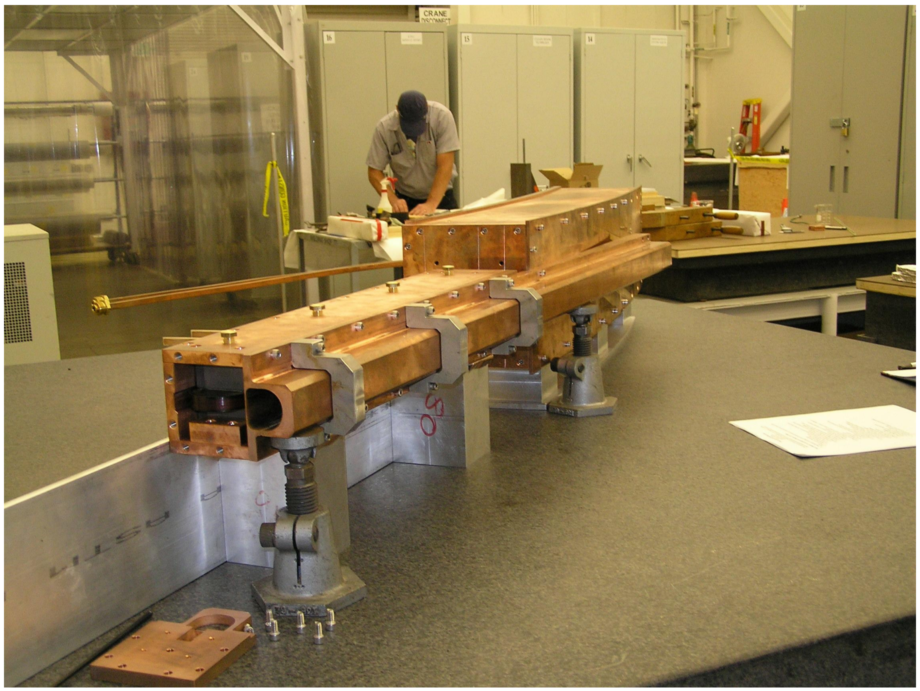


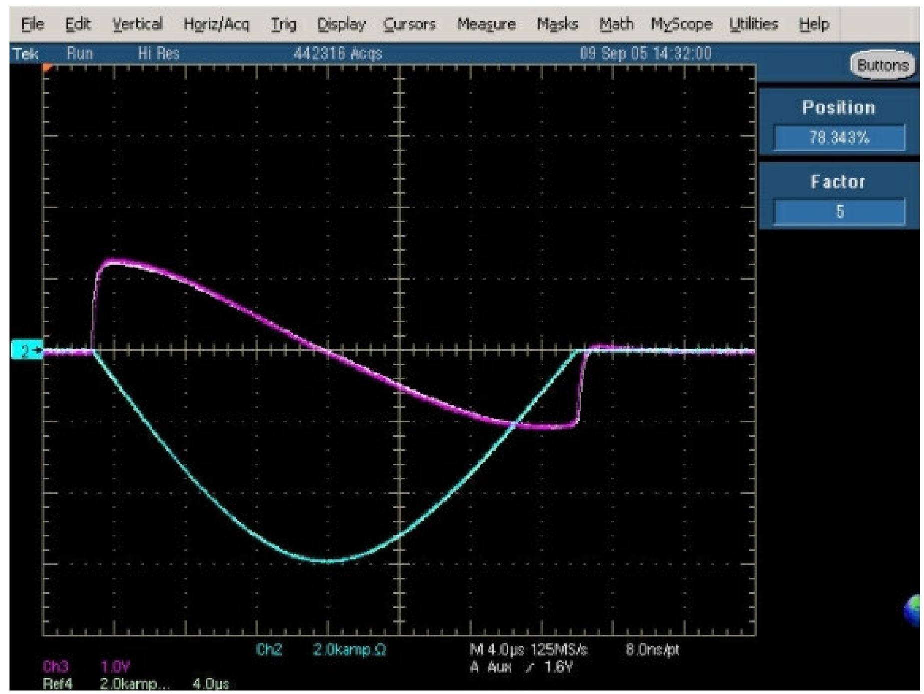
Major Accomplishments in FY05

- Conceptual Design Review of the Project in November 2004
- Received 3 M$ in FY05 from BES in March 2005
  (on top of 1 M$ earlier funding)
- Performed Extensive Testing of Pulsed Magnet Systems
- Finished Design work on major systems
- Began Procurement of the Major Long Lead Items
- Conducted Many Tests and Simulations Concerning Radiation Safety and Began Upgrading the Radiation Protection System

Tests of the Pulsed Magnet Systems

- Successfully tested each of the Pulsed Magnets at full energy
- Currently finishing (short) lifetime tests





Thin Septum Test Setup

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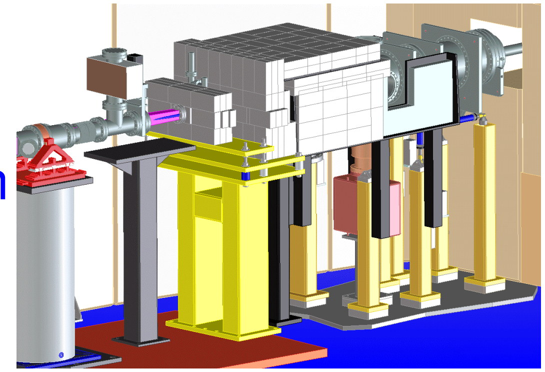
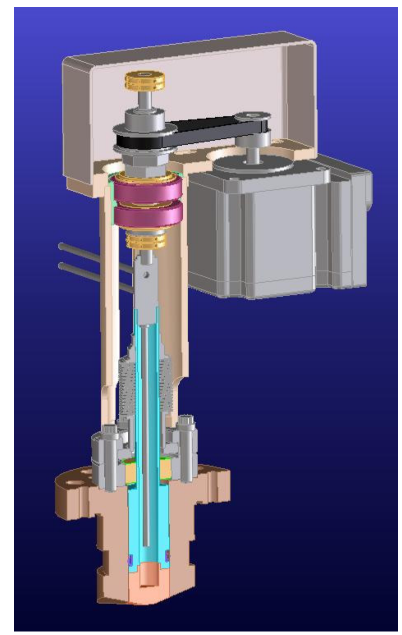
Upgrading our Radiation Protection Systems

Changes in operation after Top-Off



- Injection with the personnel safety shutters open
- Higher stored beam losses
- Injection with undulators closed

The radiation protection systems (interlocks, collimation, local shielding) will be upgraded to ensure safe operation with Top-off



- Extensive testing on beamline 4.0
  (already tested 1.5 GeV top-off with beamline 4.0 open)
- Working closely with DOE
- (External) Review in Spring 06
- ALS Safety Analysis Document (SAD) will be modified

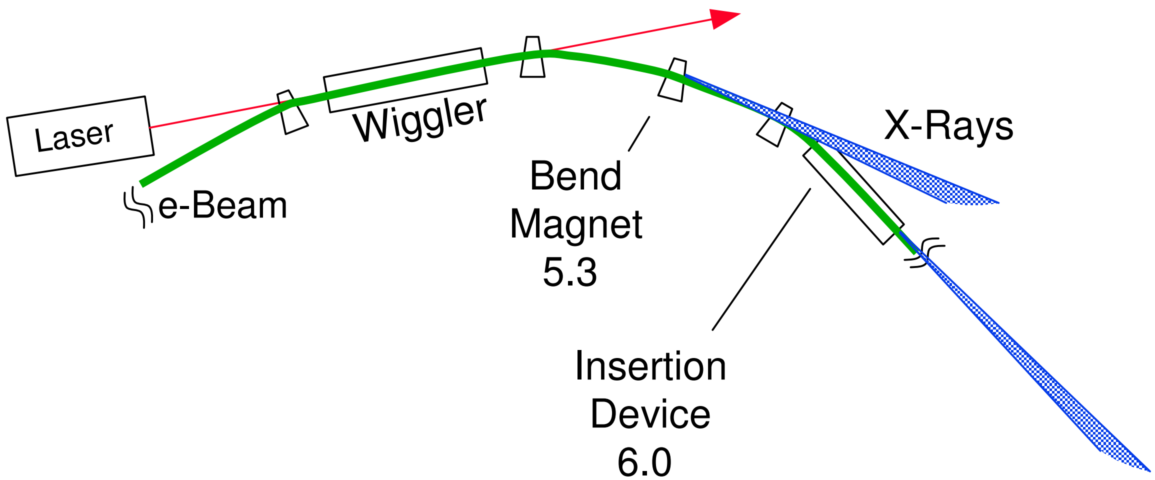
Top-Off and 2-Bunch Operation

- The present baseline scope of the Top-off upgrade does not include provisions for injecting “clean” bunches into the storage ring anymore
  - Using top-off injection during two-bunch operation, there would be some current in “untargeted bunches” that may not be acceptable for some 2-bunch users
- Techniques exist (SPRING-8, ESRF) for “cleaning” the bunches in the injector $\Rightarrow$ expensive, part of delayed scope
- It may be possible to clean bunches in storage ring during top-off, but:
  - Beam will be unstable during cleaning
  - Will require (all) users to use a gating signal (of at least 100 ms)

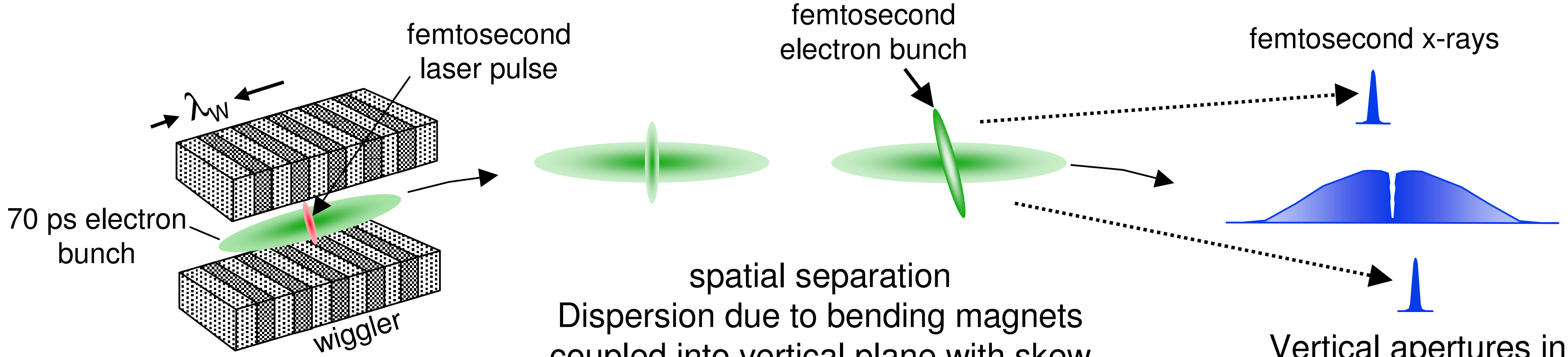
Future (Top-off) Plans

- Extended shutdown will be in Fall 2006
  - Exact date and duration to be determined (6 to 8 weeks including initial commissioning)
- Plan to operate with full-energy injection immediately following the shutdown
- Will slowly migrate to full top-off operation during the following six months

Femtoslicing with Undulator in Straight 6



200 fsec X-Ray Pulses
at 20 KHz



electron-photon
interaction in wiggler

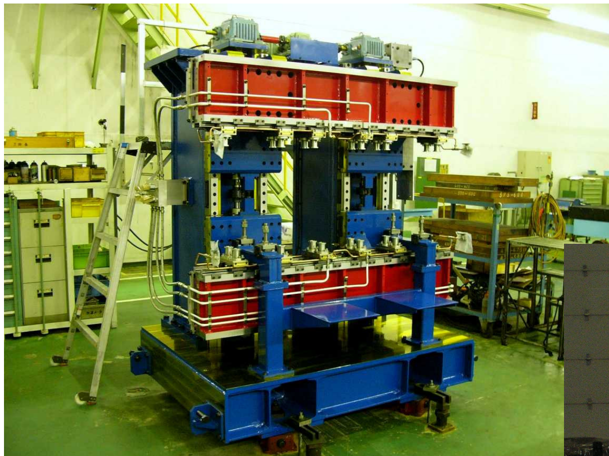
spatial separation
Dispersion due to bending magnets
coupled into vertical plane with skew
quadrupoles (closed dispersion bump).

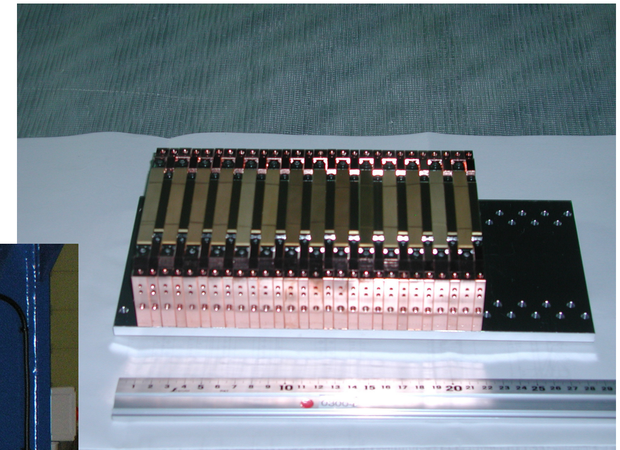
Vertical apertures in
focus plane in
undulator beamlines

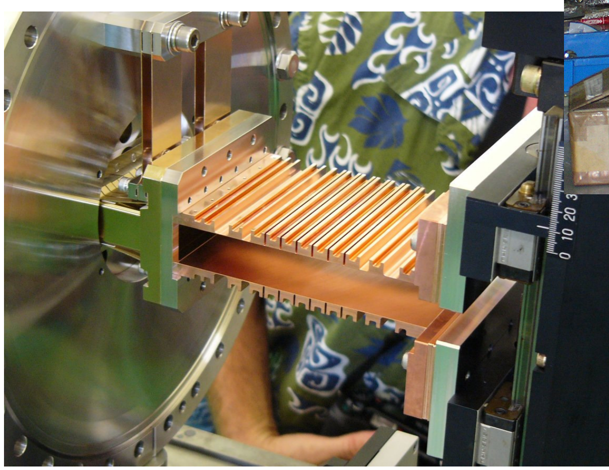
Undulator Source for fs-slicing

- Main accelerator physics challenges were:
  - Beam Dynamics impact of both insertion devices
  - Creation of sufficiently large vertical dispersion bump for spatial separation (very complex change of the local lattice in 3 arcs)
  - Reduction of vertical baseline emittance and control of beamsize stability
  - Minimum allowable gap for radiator
  - Potential radiation damage to in-vacuum undulator (especially in top-off operation)

Pictures of new IVID (Sumitomo)

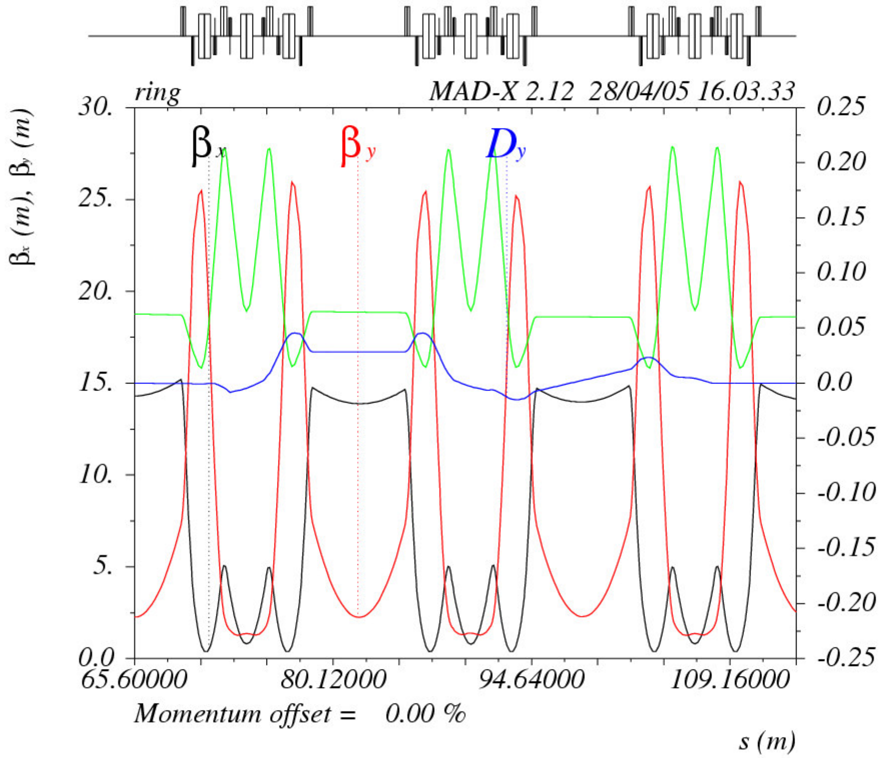


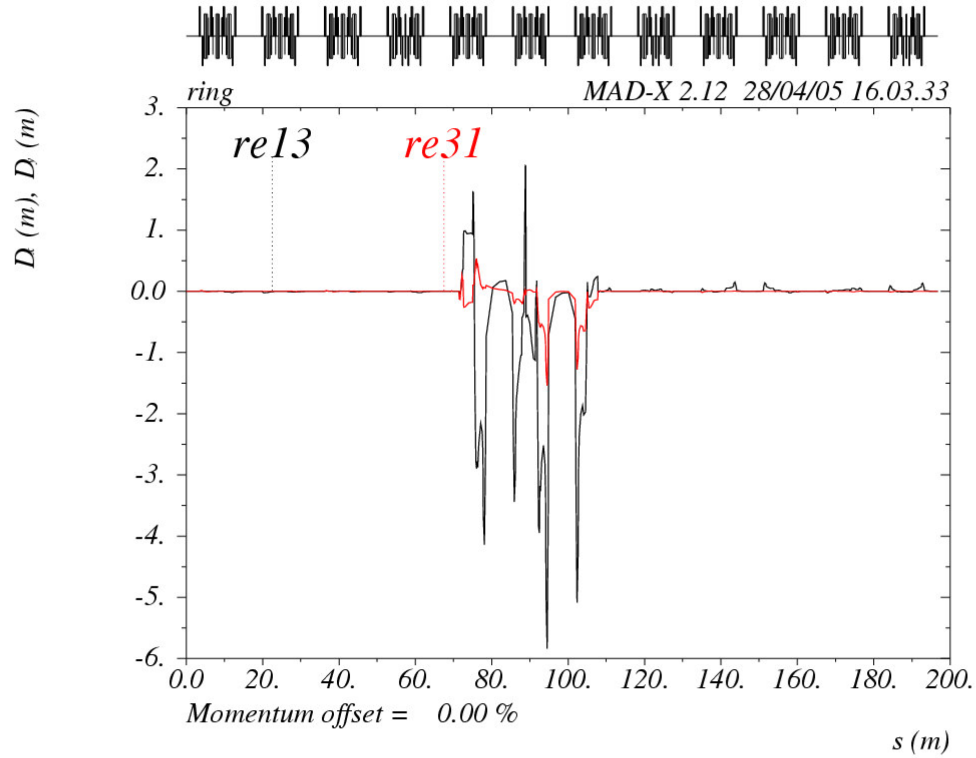




- 30 mm period, hybrid
- 50 periods
- 5.5 mm min. magnetic gap
- 1.52 T peak field

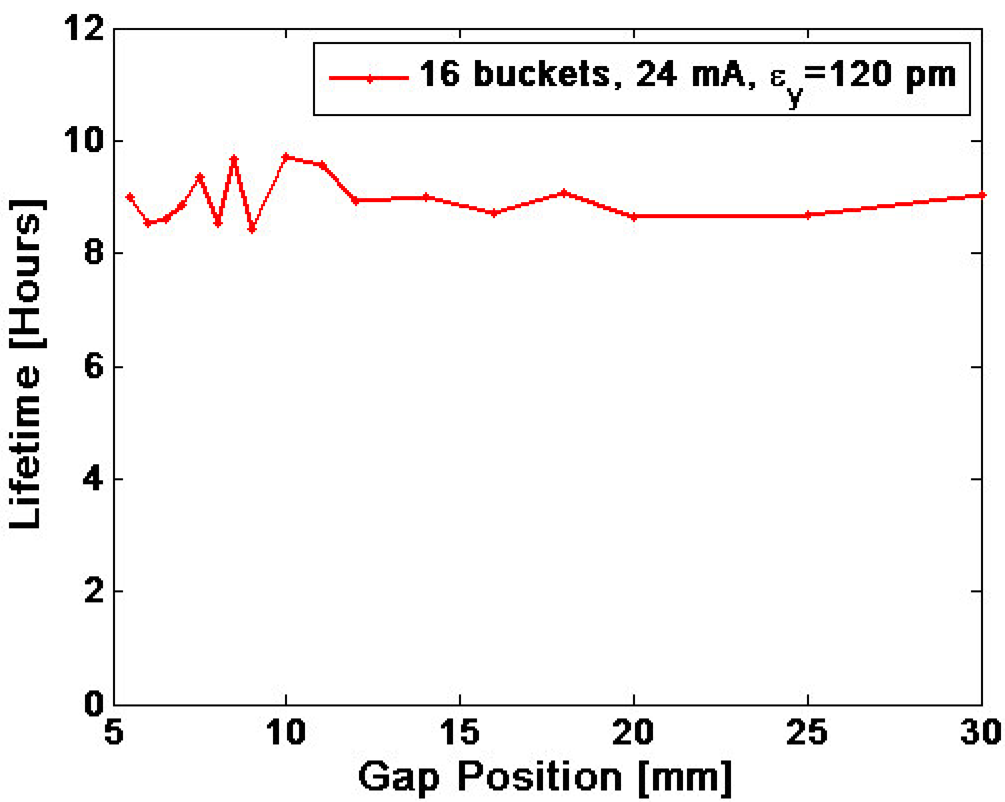
Improved dispersion bump





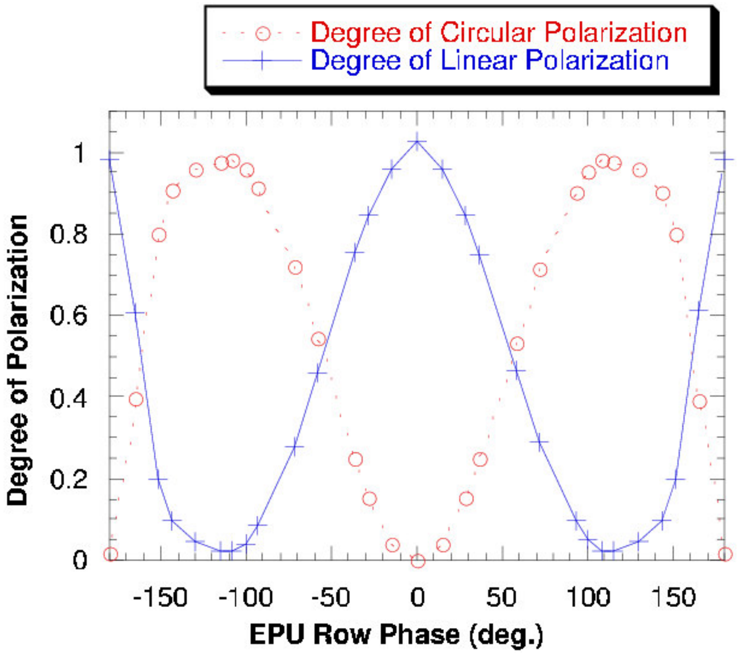
- **New higher tune lattice required modification of skew quadrupole scheme:**
  - —**Now we use 12 (old 4) skew quads, spanning 3 (old 2) arcs**
  - —**Scheme is improved in terms of beam dynamics: Locally coupling in IVID straight is near zero**

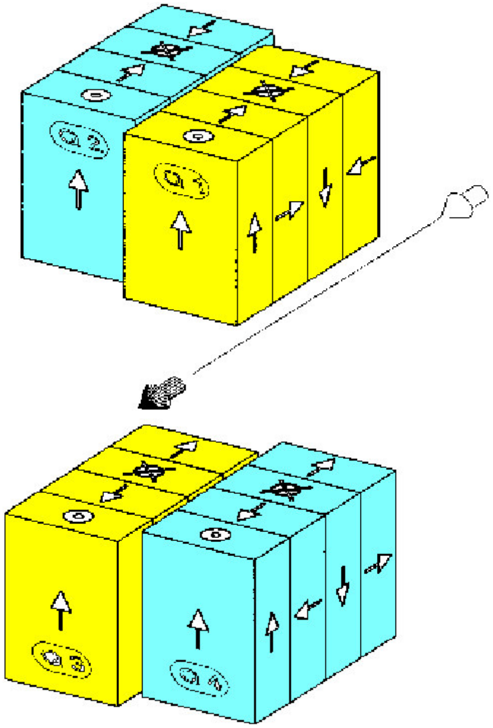
Closing IVID to minimum aperture



- Closed (magnetic) gap down to 5.5 mm
- No Touschek lifetime degradation for normal/small coupling at 1.5 mA/bunch
- No TMCI instability in two-bunch mode at 50 mA
- Are using scrapers elsewhere to avoid demagnetization (1st already installed)

APPLE-II type EPUs





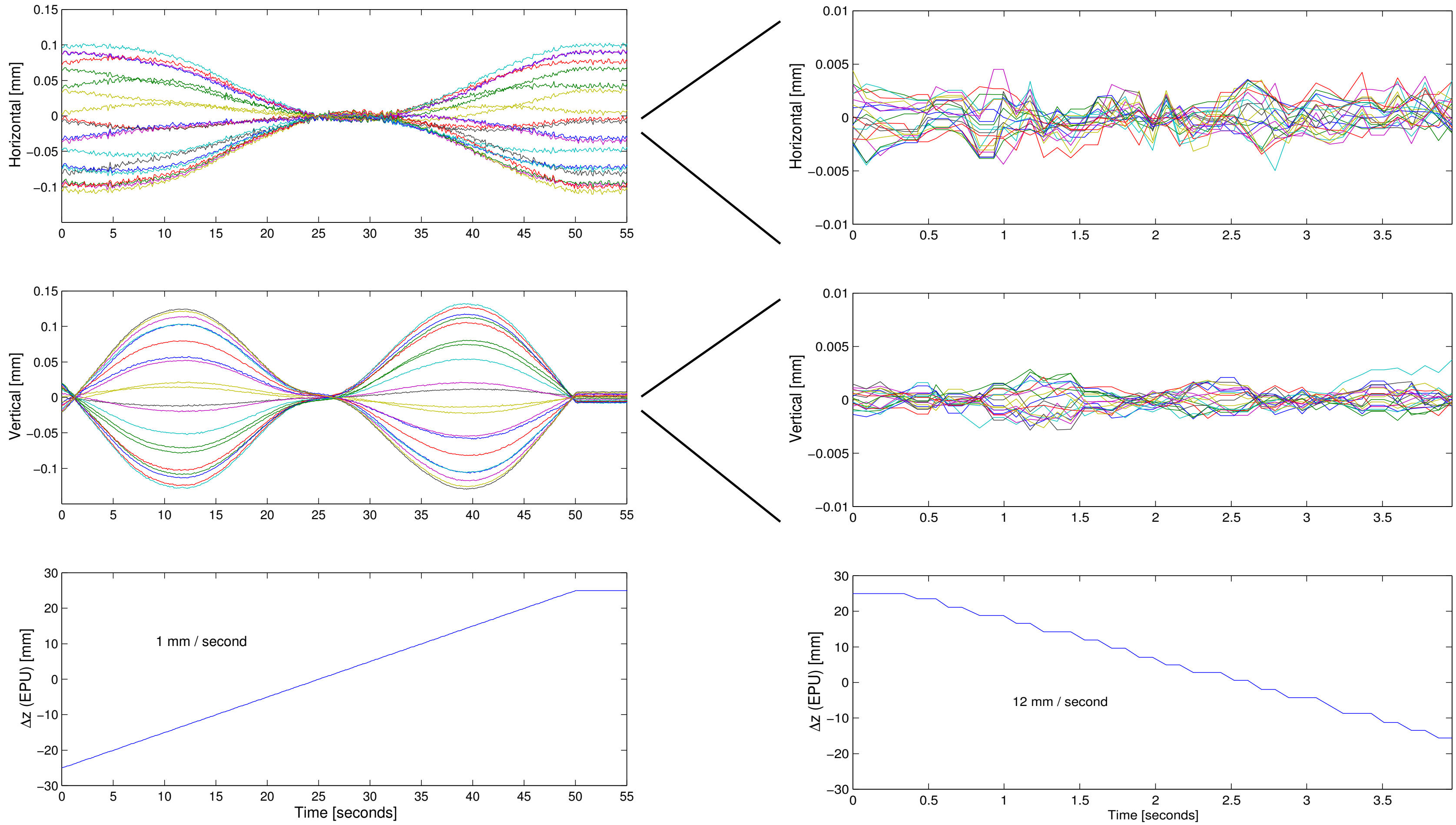
- Four quadrant pure permanent magnet undulator
- Vertical gap affects photon energy
- Longitudinal phase of two quadrants selects polarization (linear, elliptical, circular) + energy
  - Extremely important for many of core ALS science applications
  - Large expansion of number of EPUs expected at ALS

EPU effects

1. Variation of on axis field integrals with EPU phase (causing orbit distortions).
2. Variations of the (mostly vertical) beamsize (both with gap and with phase):
   - Due to focusing changes (systematic focusing terms from the bulk of the undulator).
   - Due to coupling terms (skew quadrupole like or solenoid like).
3. Higher order effects impacting the dynamic (or momentum) aperture, for example due to the field roll-off, which is quite significant and systematic in circular polarization mode.

EPU FEED FORWARD ORBIT CORRECTION

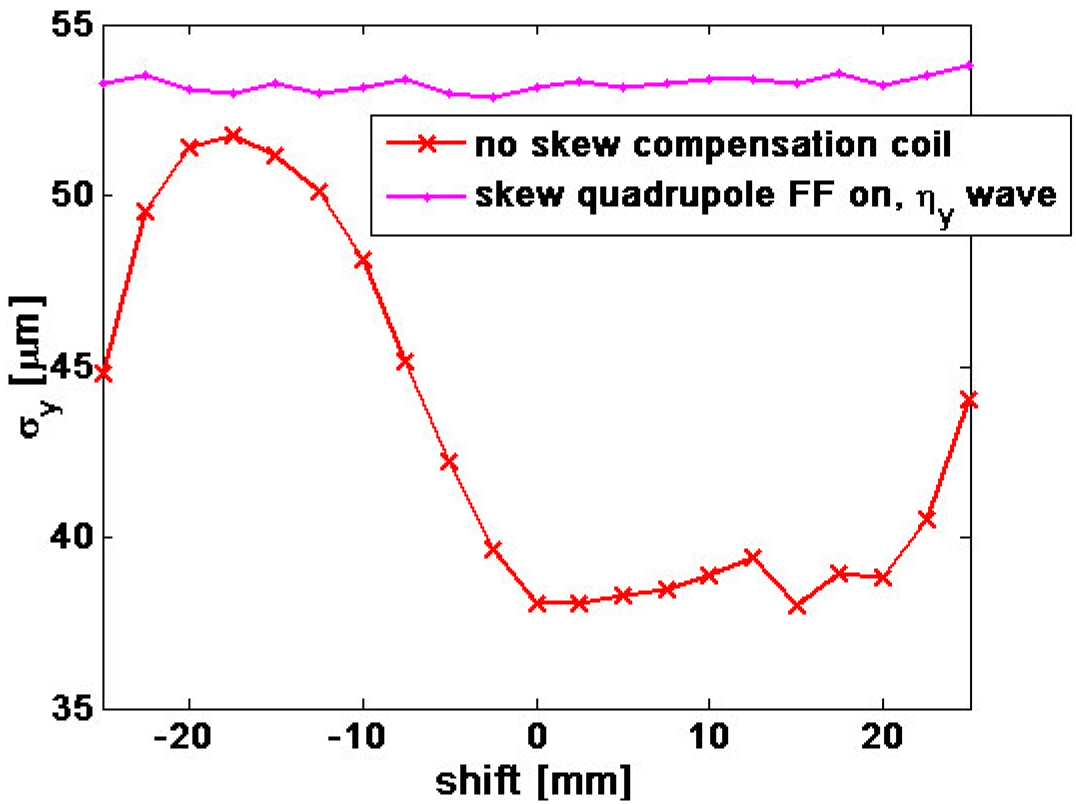
Orbit Error without Feed Forward Correction | 100 Hz Feed Forward Correction



Implemented since 2000

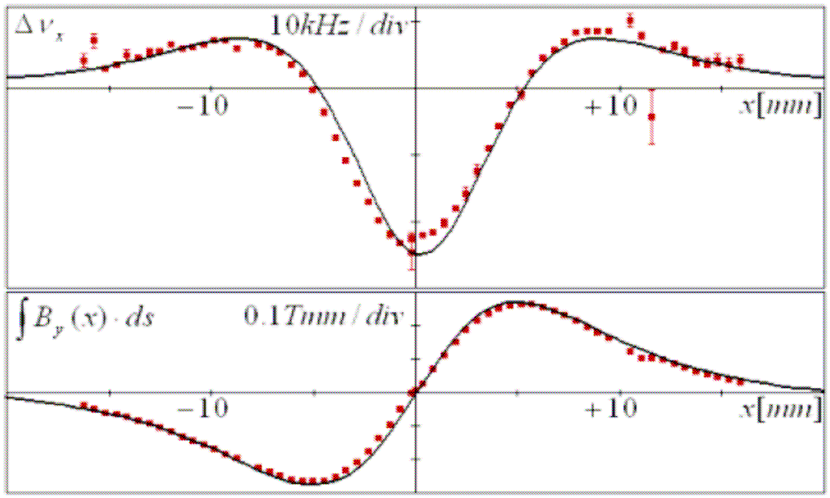
Skew quadrupole compensation for EPUs

- Beamsize variation was solved last year (2004): Installed correction coils for feedforward based compensation – routine use since June/September
- Early this year we identified the root cause: 2-3 micron correlated motion of magnet modules due to magnetic forces
- Will be able to modify design of future device such that active correction will not be necessary!

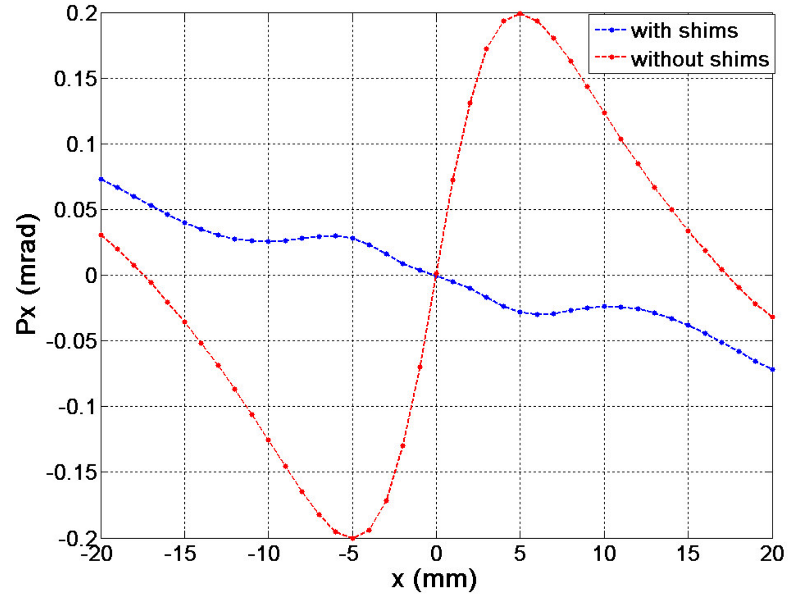


- Just for reference: Whenever an undulator moves, about 120-150 magnets are changed to compensate for the effect (slow+fast feed-forward, slow+fast feedback)

Dynamic Field Integrals



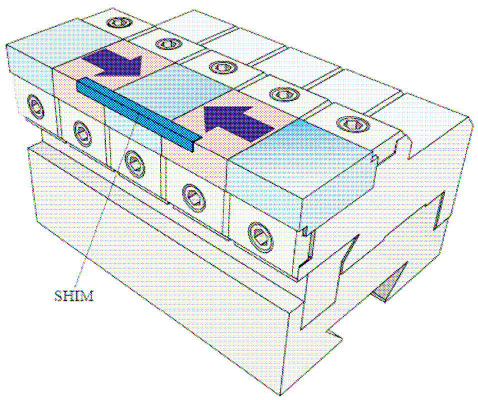
BESSY, UE52, calculated and measured dynamic field integrals

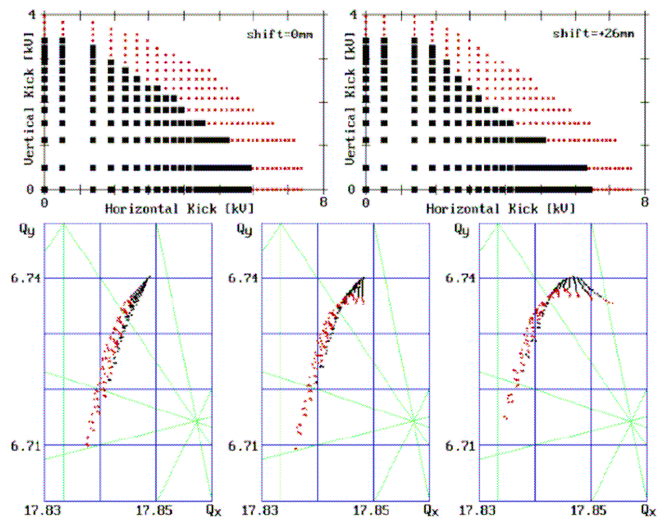


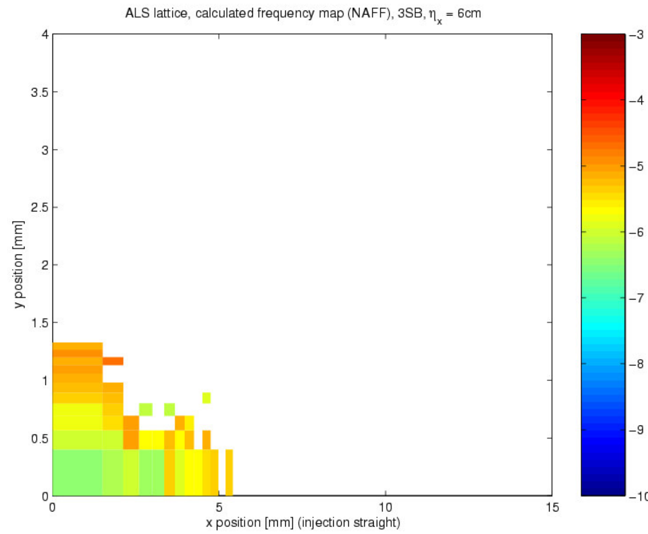
ALS, EPU90, calculated dynamic field integrals w/o and with shimming

- **Field roll-off together with undulating trajectories**
  - **No complete cancellation in one period**
- **Can generate significant so-called dynamic field integrals (worst in linear vertical polarization) – scale with period and field squared!**
- **Started intensive measurement program at ALS**

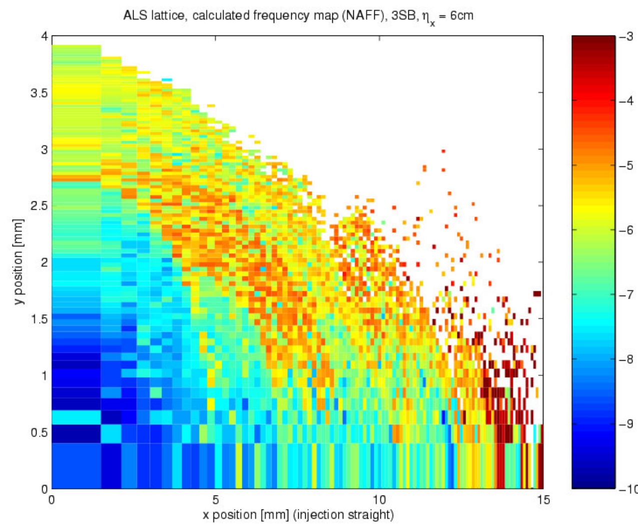
Correction with Shims







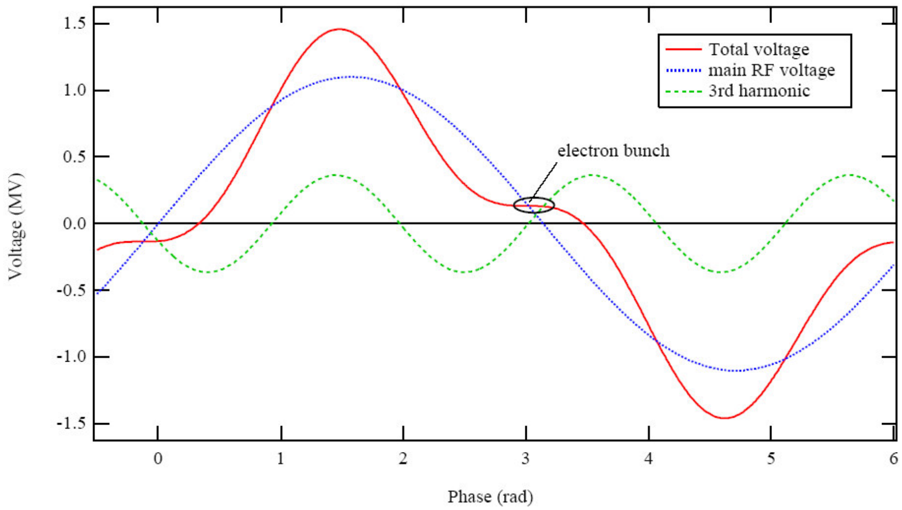
- Shims can produce real multipoles that (partially) compensate dynamic field integrals
- Systematic+successful tests at BESSY with 52 mm period EPU
- Simulations for ALS very encouraging – large expansion of number of EPUs seems possible!

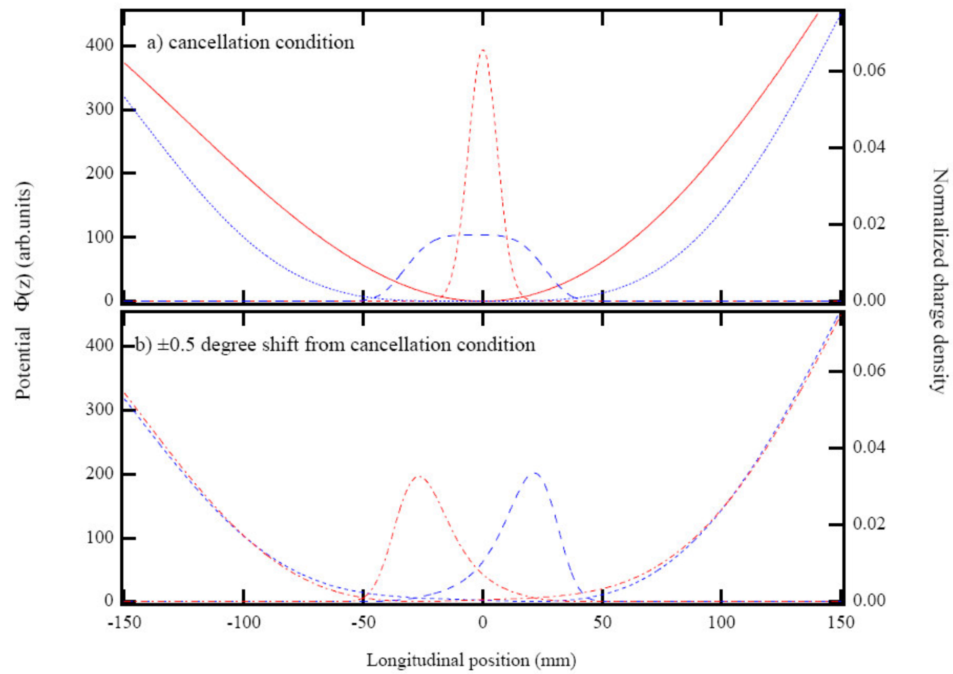


Gaps in fill pattern, phase transients, fs-Slicing

- Timing experiments use gap in fill structure or ‘camshaft’ bunch
- The particular details of the fill pattern have large impact on some key performance parameters of the ALS
  - —Lifetime
  - —Bunch length
  - —Synchronous phase/phase variation
- Underlying reason is fundamental process of beam loading
- Fs-Slicing upgrade will (at some point in the future) require smaller phase transients than we have now.
- Quantitatively: Smaller fill pattern gaps can provide
  - —Potential lifetime increase up to 50%
  - —Reduced phase transient to facilitate laser synchronization.

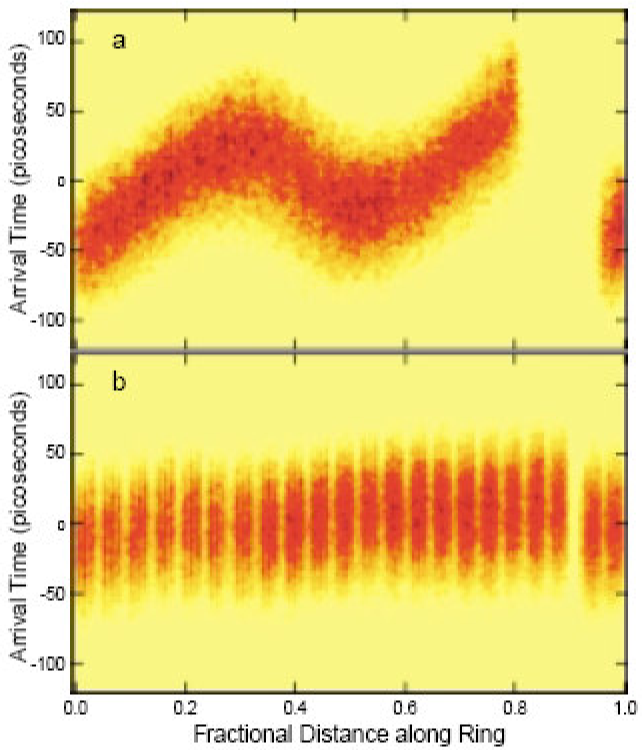
Phase transients

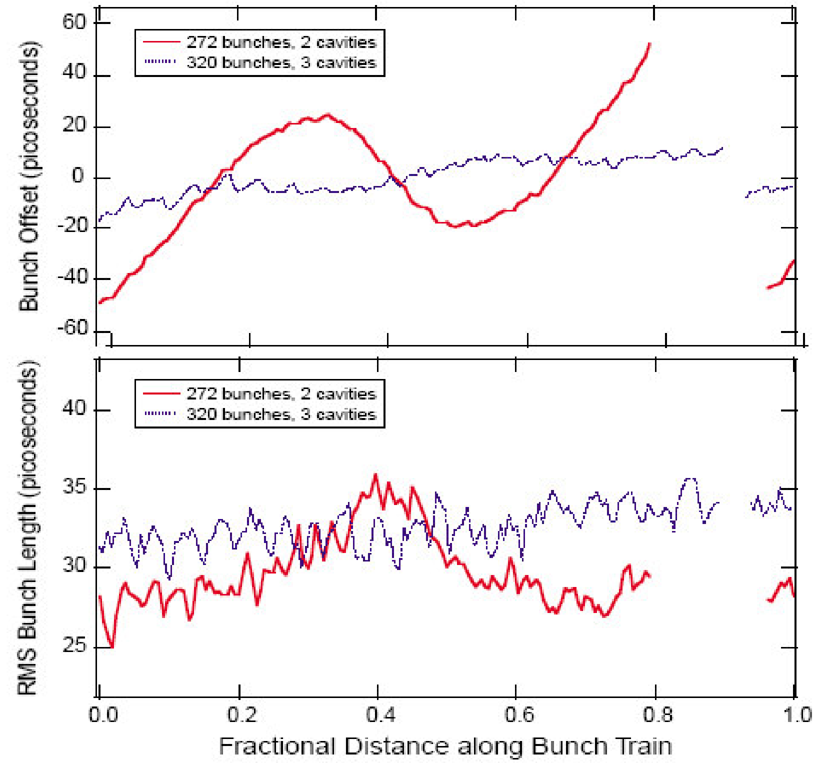




- Circulating beam induces field in cavities (both main accelerating acvities and third harmonic cavities)
- Any deviation from homogeneous filling, like a gap in fill structure induces transient field variation – both amplitude and phase
- This variation acts back on beam and generates bunch length and synchronous phase variations along bunch train
- Effect gets amplified by bunch lengthening of THC – flattened potential

Camshaft, Lifetime, Phase Transients





- Synchronous phase varies by more than the bunch length over the length of the bunch train.
- Effect is current and fill pattern dependent (i.e. time dependent)
- This presents big challenge for laser synchronization, etc.
- Heads up: At some point in the future this will be incompatible.

What is next …

- Beamline commissioning of fs-slicing upgrade has started, will continue for several months
- One more set of main RF HOM dampers in January
- Top-off shutdown and initial commissioning in late summer, early fall 2006
  - —In preparation:
    - Additional scrapers/collimators in January/February
    - Upgrade of pulsed magnets during spring/summer
    - Installation of new radiation monitors, …
- MERLIN EPU (long period, quasi periodic) towards end of 2006
- Further improvements in orbit stability/feedbacks
  - —We are already at the forefront of light sources, but we believe we will need to improve further (smaller vertical emittances)

What we are thinking about

- Other medium to long term items we are thinking about (or have started to think about):
  - —Further insertion device development
  - —(sub)picosecond source/crab cavities
  - —Flexible bunch (light) patterns using fast kickers
  - —Exploring how to better use some straight section space
  - —CIRCE (broadband coherent far infrared source)
  - —Control System Upgrade and other Upgrades/Replacements necessary for Reliability
  - —Larger scale ALS upgrades

Conclusions

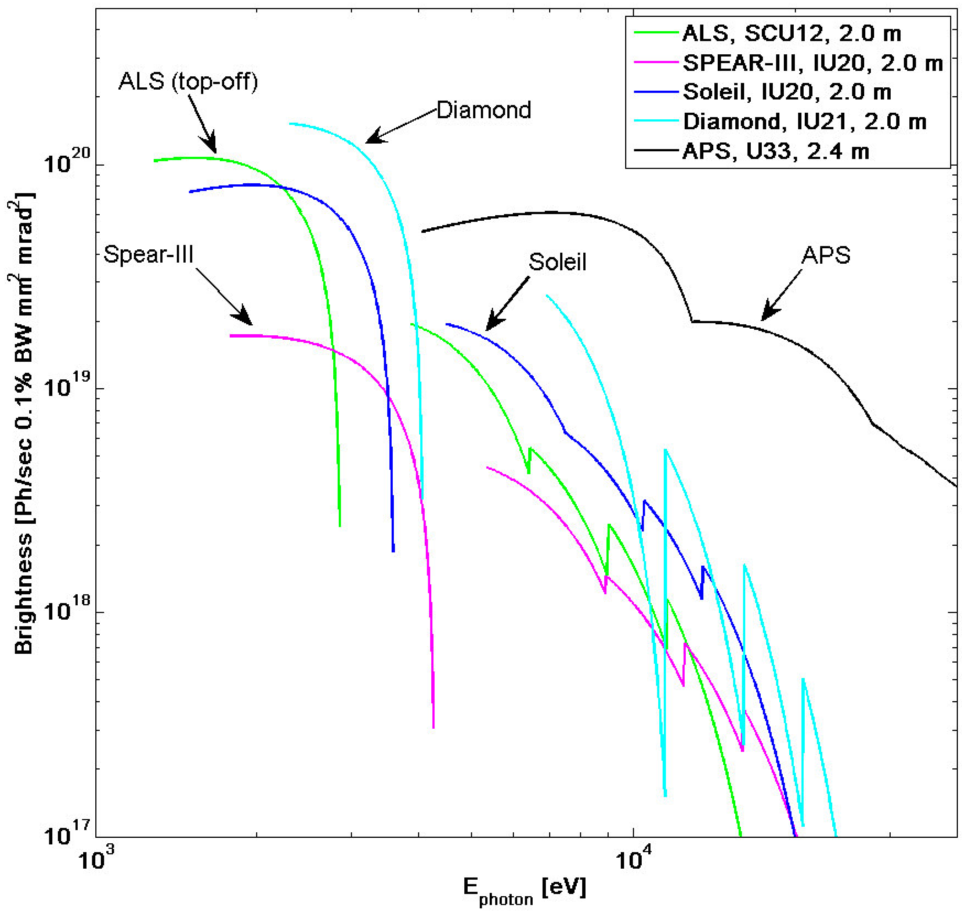
- ALS is a world class soft x-ray source with >2000 users annually
- Performance is constantly evolving (stability, …) and despite increasing complexity and ageing, reliability is very high
- Short term upgrades are well under way:
  - —Fs-slicing
  - —Top-off
  - —Longer period EPUs
- We also started to develop some medium and long term thoughts including potential major upgrades

Credits

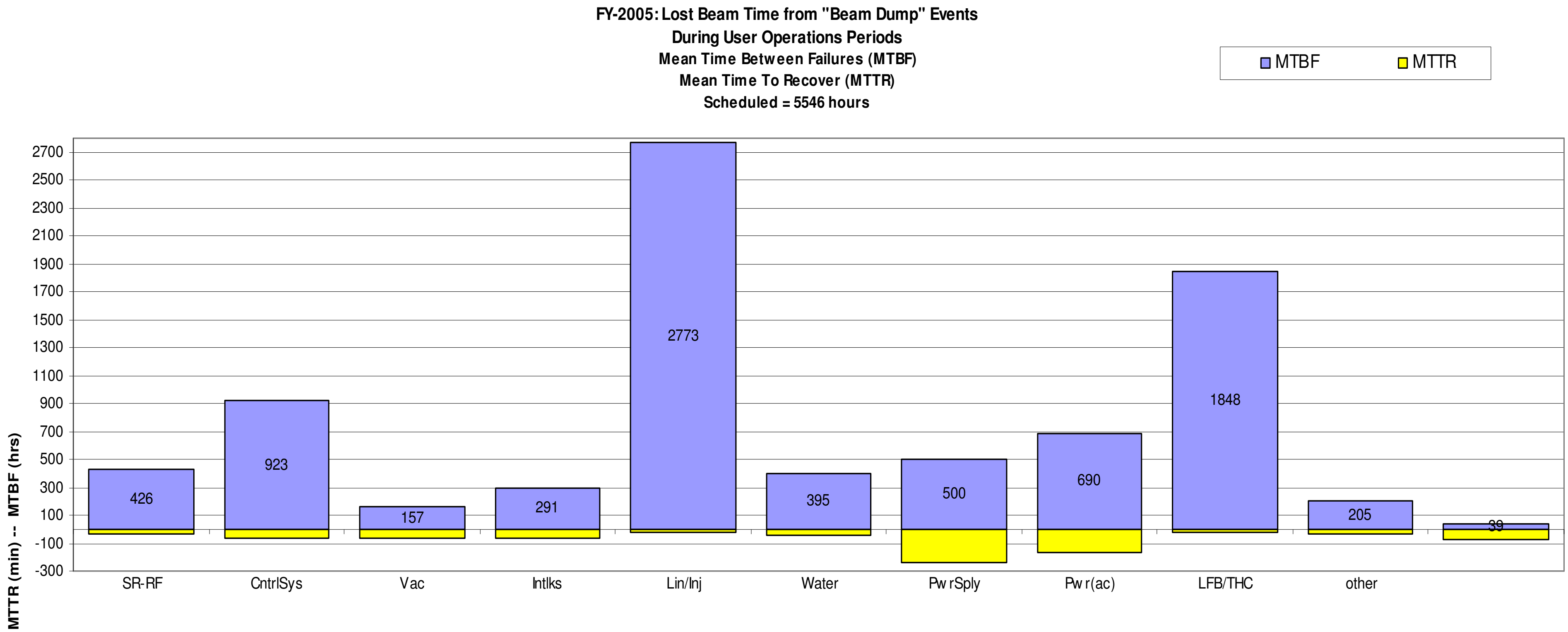
- What I have presented is the work of many people:
  - ALS AP: W. Byrne, H. Nishimura, G. Portmann, D. Robin, F. Sannibale, T. Scarvie, C. Steier, W. Wan, W. Wittmer
  - ALS ME: R. Duarte, R. Schlueter, et al.
  - ALS EE: W. Barry, et al.
  - ALS Controls: A. Biocca, et al.
  - CBP: A. Zholents, J. Corlett, S. Lidia, D. Li, J. Byrd, …
  - ALS: T. Warwick, B. Schoenlein, H. Padmore, S. Rossi, …
  - SPEAR: J. Safranek, A. Terebilo, …

Brightness comparison 2007

- With top-off machine parameters and future insertion devices (s/c Nb_3Sn) ALS becomes competitive with newer medium energy light sources even around 10 keV
- APS/ESRF/Spring-8 are of course still higher in brightness in this hard x-ray region



Availability, Reliability, MTBF



- **Last year has been a good year in terms of reliability!**
  - **About 96.4% availability = beam time delivered/scheduled**
  - **Mean time between failure during user operation periods about 39 hours**